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Carbon dots production via pyrolysis of sago waste as potential probe for metal ions sensing

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ABSTRACT

This work reports the synthesis of carbon dots (C-dots) from sago industrial waste using thermal pyrolysis approach. The pyrolysis condition was found to govern the carbonisation conversion of bulk sago waste into carbon rich residue that can be further isolated to obtain carbon dots. In order to obtain the best yield of the carbon dots, optimization of the thermal pyrolysis conditions have been performed which consisted of varying temperature of carbonisation at a constant heating duration. The C-dots can be dispersed in aqueous media and portrayed a significant fluorescent property that can be observed by naked eye under a UV light source. The optimum temperature of carbonisation was determined at 400 °C in which the strongest fluorescence emission was record at 390 nm with the optimum excitation wavelength of 315 nm. The fluorescence of the C-dots was found to be significantly quenched in the presence of various metal ions. Thus, the C-dots can be adopted as a potential optical probe for sensing of metal ions in aqueous media. An analytical characterization has been performed in this study over a series of commonly available metal ions and the sensing characteristics were evaluated using the standard Stern–Volmer quenching model. This study has successfully demonstrated an innovative approach of converting agricultural waste into high value optical sensing receptors for metal ions detection.

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1. Introduction

In the recent years, fluorescent carbon nanoparticles or carbon dots (C-dots) have drawn considerable interest due to their stable photoluminescence property, and broad ranges of excitation and emission spectra. They have 'almost-spherical' shapes and are synthesizable via relatively simple methods from various starting precursors [1]. Ideally, C-dots were reported to have stable photoluminescence (PL) properties, great biocompatibility, and low cytotoxicity effects towards biological components as compared to their counterparts, the semiconductor quantum dots (Q-dots) [2,3]. Q-dots are generally toxic and have been known of affecting health and environmental conditions as it comprised of elements from the periodic groups II–VI, III–V or IV–VI [3,4]. C-dots have since then known to be important and stand to have huge impact along with their promising applications and preliminary outcomes in various fields [5].

The synthetic routes of these non-toxic fluorescing C-dots include arc-discharge, acid dehydration, electrochemical oxidation, laser ablation, hydrothermal reaction, and combustion (thermal) supported methods, which in general can be categorized into: (i) top-down and (ii) bottom-up methods [1,4,6]. Majority of the synthesis methods require complicated equipments, catalysts, non-environmental friendly chemicals or harsh experimental conditions which results in expensive production costs. Thus, there is on-going focus on the development of simple and economical methods to synthesize C-dots [2]. Among those, combustion (thermal) supported methods, otherwise, known as pyrolysis of carbonaceous materials is a simple, clean and inexpensive synthetic option [7–10]. Thermal degradation synthesis routes have shown to be successful via microwave- and furnace- assisted pyrolysis as demonstrated by Yang et al. [11], Liu et al. [3], and Wang et al. [12]. Pyrolysis parameters such as type of reactor system, heating temperature, pressure, presence of catalysts, and heating duration are found to affect the composition and yield of the end-products depending on [9].

There are varieties of carbon-rich starting precursors that can be used to synthesize C-dots. Along with the uprising global awareness of creating a sustainable community via waste minimization, the choice of recycling and reusing carbon-rich waste as starting

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materials for synthesis of C-dots will be of advantage. Besides, wastes are inexpensive and renewable resources, whereas some biomass wastes have been demonstrated as suitable starting precursors for the synthesis of C-dots [13–15].

In addition to the effort of searching for alternative synthesis routes and precursors, there is also an increase of interest that focuses on the practical application of C-dots. The applications of C-dots as fluorescence probe for optical sensing of metal ions have been studied by several researchers and the outcomes of their studies were promising. The C-dots were able to selectively and sensitively detect metal ions in aqueous solution [3,16,17]. The presence of toxic heavy metal ions in the environment, particularly in aquatic systems remains as one of the major environmental concerns to-date [18]. Highly selective and sensitive analytical methods such as atomic absorption spectroscopy [19,20], liquid chromatography [21–23], adsorptive stripping voltammetry [24], electrochemical analysis [25] and spectrophotometric analysis [26] have been used to qualify and quantify the levels of metal ions in the environment. Yet, these analytical methods require high operating cost, use of hazardous chemicals and involvement of tedious preparation procedures. Hence, it is not feasible and sustainable in long-term and there is a need to develop alternative analytical methods that are more economical, selective, sensitive, remains user-friendly and green to the environment. Fluorescence quenching has shown to be one of the promising alternative approaches for metal ions detection [27]. Previously, Q-dots based fluorescent probes derived from silicon, and heavy metals such as lead and cadmium have been evaluated for optical sensing application [28]. Nonetheless, the toxicity effect and possible leaching of heavy metals from Q-dots remains a challenge that significantly limits their practical applications. Alternatively, C-dots that exhibit equivalent fluorescence characteristics as Q-dots yet possessing lower toxicity and production cost may serve as potential fluorescing nanomaterial for optical sensing of metal ions.

In search for a simple alternative synthesis route of C-dots from low cost starting material, the sago waste from the industry has been chosen in this study. Particularly in East Malaysia, the sago starch industry is one of the major food industries producing approximately 260 tonnes of sago wastes consisting of woody bark, wastewater and fibrous sago pith. These wastes are usually disposed to the nearby streams and consequently resulting in an increase of pollution load [29]. Hence, this study will demonstrate the conversion of sago industrial waste into fluorescing C-dots, a biotechnological approach to recycle and reuse the sago industrial waste. The synthesis method involved the pyrolysis of sago industrial waste in a laboratory furnace which is simple and economical. Heating temperatures between 250 °C and 450 °C were investigated to carbonize the sago industrial waste into carbon residues. Experimental parameters, particularly the heating temperature relating to the pyrolysis of starting materials were evaluated to obtain C-dots with optimum optical property. The optical sensing potential of the C-dots for metal ions has been studied and its analytical characteristics were evaluated and discussed.

2. Experimental

2.1. Materials and reagents

Sago industrial waste as starting precursor was obtained from local sago industry (Bau, Kuching, Sarawak, Malaysia). The waste was pre-dried in a drying oven for a week at 40 °C and was later ground into powder with a grinder. All chemicals involved in the study were of reagent grade and used without further purification. Metal salts of $Cu(NO_3)_2$, $Cr(NO_3)_2$, $Co(NO_3)_2$, $Ni(NO_3)_2$, $Al(NO_3)_3$, $Ca(NO_3)_2$, $Pb(NO_3)_2$, $Zn(NO_3)_2$, $SnCl_2$ and $HgCl_2$ were all purchased from R&M Marketing (Malaysia). Ultrapure water obtained from MiliporeMili-Q Advantage-A10 and Millipore Elix-5 water purification system (~18.2 Ω, 25 °C) was used as solvent system throughout the experimental work.

2.2. C-dots synthesis

C-dots were prepared via pyrolysis method as illustrated in Fig. 1. In brief, appropriate mass of pre-dried and ground sago waste was weighed into a crucible and transferred into a laboratory furnace (Carbolite ELF 11/14 B). The sample was heated from room temperature to a final temperature (ranging from 250 °C to 450 °C), with no gas flow and kept at the set temperature for 1 h. After the heating process, the resulting product was allowed to cool to room temperature in a desiccator before a mixture with a mass concentration of 10 g/L was prepared. Briefly, an exact amount of 0.0100 g of heat treated sago waste was weighed into a volumetric flask and dispersed with 10 mL of ultrapure water. The mixture was then homogenized under sonication (Branson 5510 Ultrasonic cleaner) for 2 h and was later subjected to centrifugation (EppendorfMinispin) at 13,400 rpm for 20 min to remove the bulk particles. The supernatant was finally collected and diluted to a ratio of 1:2 for optical analysis.

2.3. Instrumentation

Fluorescence measurements were recorded using fluorescence spectrophotometer (Varian Cary Eclipse Fluorescence Spectrophotometer). The isolated C-dots were diluted with ultrapure water to an appropriate concentration and then transferred into a quartz cuvette of four clear windows with a path length of 1 cm. The settings of excitation and emission wavelengths were adjusted accordingly for C-dots samples treated at different conditions to obtain its respective highest emission intensity. The excitation and emission slits of the fluorescence spectrophotometer were both set at 5 nm for all measurements. UV absorbance of samples was determined via UV–visible spectrophotometer (Varian Cary 50 Conc UV-Visible Spectrophotometer). Similar concentrations of C-dots as prepared for the fluorescence analysis were used and measurements were made in a quartz cuvette with two clear windows and a path length of 1 cm. The absorbance of samples was monitored between 200 nm and 800 nm. Ultrapure water was used as reagent blank for both instruments. Scanning Electron Microscope (SEM) (JEOL JSM-6930 LA) operated at zeta potential of 10 kV was used to characterize the physical properties of synthesized C-dots. Sample for SEM analysis was prepared by dispensing 10 μL of supernatant containing C-dots onto a 1 cm × 1 cm platinum plate. The plate was placed in a dessicator overnight to concentrate C-dots by removing water. SEM images of samples were analyzed via SmileView (JEOL version 2.2) for estimation of particle sizes. Fourier Transformed Infrared (FTIR) (Perkin-Elmer) was used to characterize the organic functional groups on C-dots. The supernatant containing C-dots was concentrated by removing water under vacuum, in a freeze dryer (LABCONCO FreezeZone 6 Freeze Dryer). The resulting solid residue was then used for the analysis.

2.4. Optimization of pyrolysis variables

The effects of temperature of the furnace on the photoluminescence of C-dots derived from sago waste were investigated. In this work, the intensity of the fluorescence of the isolated product was used as a measure on the production efficiency of the C-dots. It is derived that higher intensity recorded denotes larger amount of C-dots produced. A series of end-heating temperatures were fixed from 250 °C to 450 °C at an interval of 50 °C and each of the heating process was left to stand for an hour. Besides evaluating the

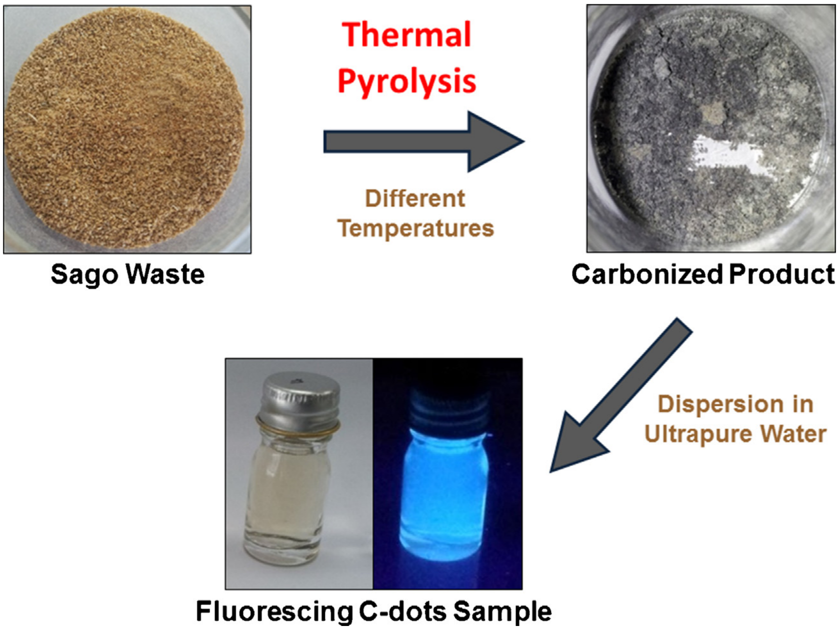

Fig. 1. Synthesis route of C-dots.

production efficiency of C-dots, the effect of different carbonisation temperatures towards the weight loss of the starting precursor was also studied. The percentage of weight loss was calculated based on the differences in mass of initial starting precursor and the product residue after heating and cooling to room temperature.

3. Results and discussion

3.1. Characterization of C-dots

Prior to pyrolysis, the particle sizes of grinded raw sago waste were in the range of 10 μm to 15 μm. The particle sizes of processed sago waste were significantly reduced after thermal decomposition at different temperature, Fig. 2 shows the SEM images of C-dots derived from sago waste samples treated at 250 °C (Fig. 2(A)) and 400 °C (Fig. 2(B)), respectively. Large clusters of particles with irregular shapes were observed on C-dots sample treated at 250 °C. The sizes of the particles were in the range of 37 nm to 66 nm. Contrarily, C-dots have more uniform spherical shapes when treated at 400 °C and their physical characteristics were similar to those described in the literatures [1,2]. The particles were well dispersed with sizes in the range of 6–17 nm.

FTIR was used to identify the organic functional groups on C-dots. The FTIR spectra of untreated sago waste sample and sago waste sample treated at 250 °C were shown in Fig. 2(C) and (D) respectively. Both spectra show relatively similar characteristic absorption peaks, indicating the presence of similar functional groups in both samples. FTIR spectrum of C-dots sample treated at 250 °C showed characteristic absorption peaks of —OH in the alcohol or phenol group at 3394.60 cm^{-1}, the stretching vibration band of alkyl C—H bond at 2928.54 cm^{-1}, the stretching vibration band of C═O bond in the carboxylic acid and amide groups at 1718.72 cm^{-1} and 1633.51 cm^{-1}, respectively and the bending vibration band of aromatic C—H bond at 862.14 cm^{-1}, suggesting the presence of alcohol or phenol, alkyl, carboxylic acid, amide and aromatic groups. This gives an indication that combustion of sago waste at 250 °C was not entirely complete. Initial devolatization and carbonization of lignin and cellulose in biomass were only found to start to occur at temperature between 200 °C and 280 °C, followed by the release of carbon dioxide, acetic acid and additional moisture [30,31]. The presence of carboxylic group in the absorption spectrum of sample treated at 250 °C gives an indication of incomplete devolatization and carbonization of cellulose and lignin residues [32]. As for sample treated at 400 °C (Fig 2(E)), it shows characteristic absorption peaks of alcohol–OH bond at 3420.55 cm^{-1}, bending vibration band of C-H bond in the group of alkane and stretching vibration of C—O bond in the group of alcohol at 1118.57 cm^{-1}, suggesting the presence of alcohol and alkane groups. Complete combustion will occur and causes severe decomposition of different functionalities. It was suggested that most of the carbon dioxide releasing groups have been removed and leaving only a small amount of C—O group on the carbon surface [33].

3.2. Effect of pyrolysis conditions

Sago waste sample was subjected to thermal degradation at different heating temperatures. Significant differences in physical appearances of the end-product were observed when treated at different heating temperatures. As shown at Fig. 3, the starting precursor of sago waste was golden brown in colour before heat treated in the furnace. Once heated at 250 °C, a dark brown colour final residue was yielded. Some of the sections remained as golden brown colour indicating incomplete decomposition. As for sample treated at 300 °C, a black colour final product was observed throughout and showing better carbonisation of sago waste. Both samples treated at 350 °C and 400 °C yielded a mixture of black colour product with minor ashy grey content. As for sample treated at 450 °C, it yielded ashy final product due to excessive decomposition of the sago waste into ashes at this temperature.

From the visual observations on the products obtained after pyrolysis, it was suggested that drying process occurred at the initial stage of treatment process. When the temperature was raised above 200 °C, a portion of hemicelluloses moieties present will be decomposed into gaseous and char products along with the initial devolatilization and carbonisation of lignin and cellulose constituents in the waste, which was also suggested in the work by Uslu et al. [30]. At this stage, the materials turned brown and began to release carbon dioxide, acetic acid and the extra moisture trapped in the sample. As the heating temperature was raised higher, components such as carbon monoxide, hydrocarbons,

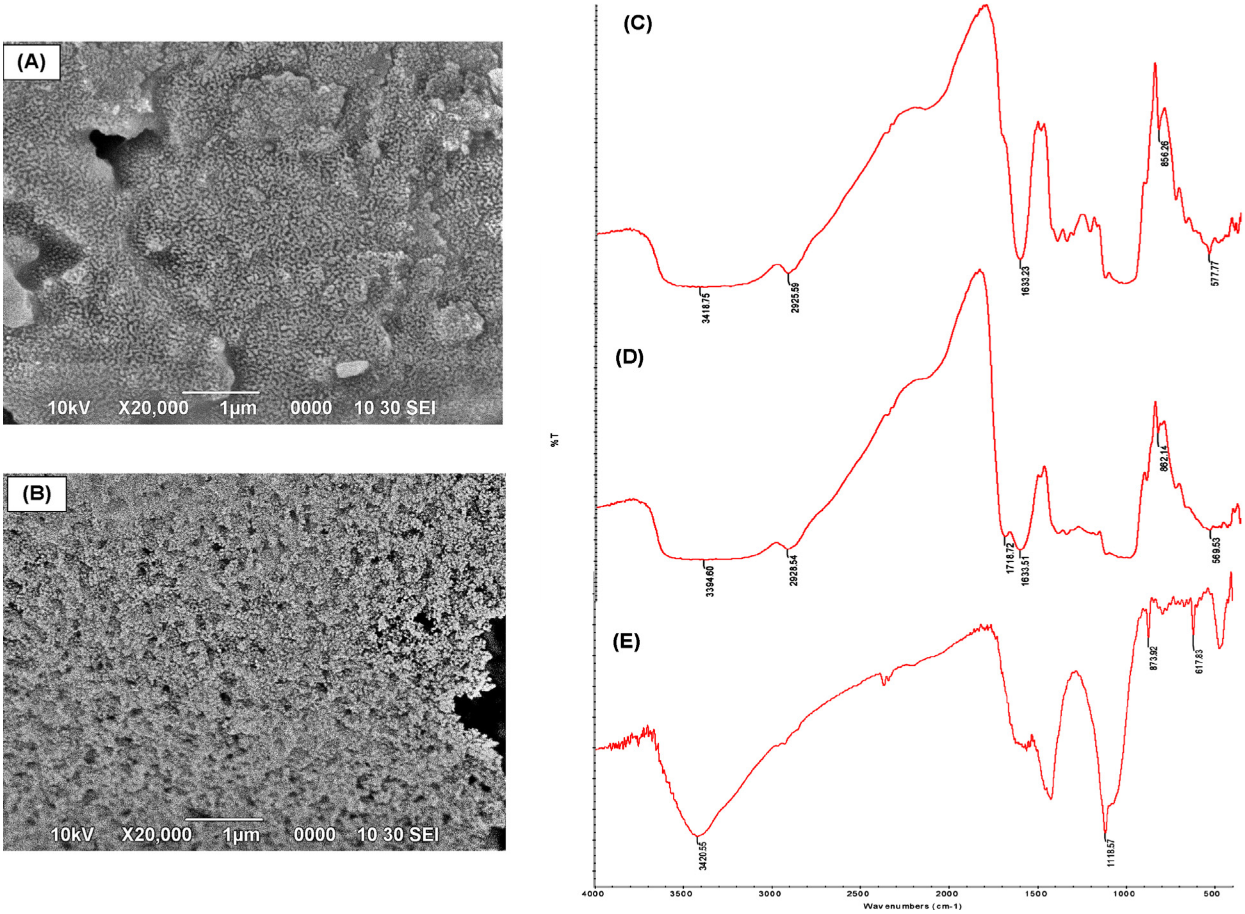

Fig. 2. SEM images of C-dots prepared from sago waste sample treated at (A) 250 °C and (B) 400 °C, and FTIR absorption spectra for (C) untreated sago waste sample, (D) sago waste sample treated at 250 °C and (E) 400 °C, respectively.

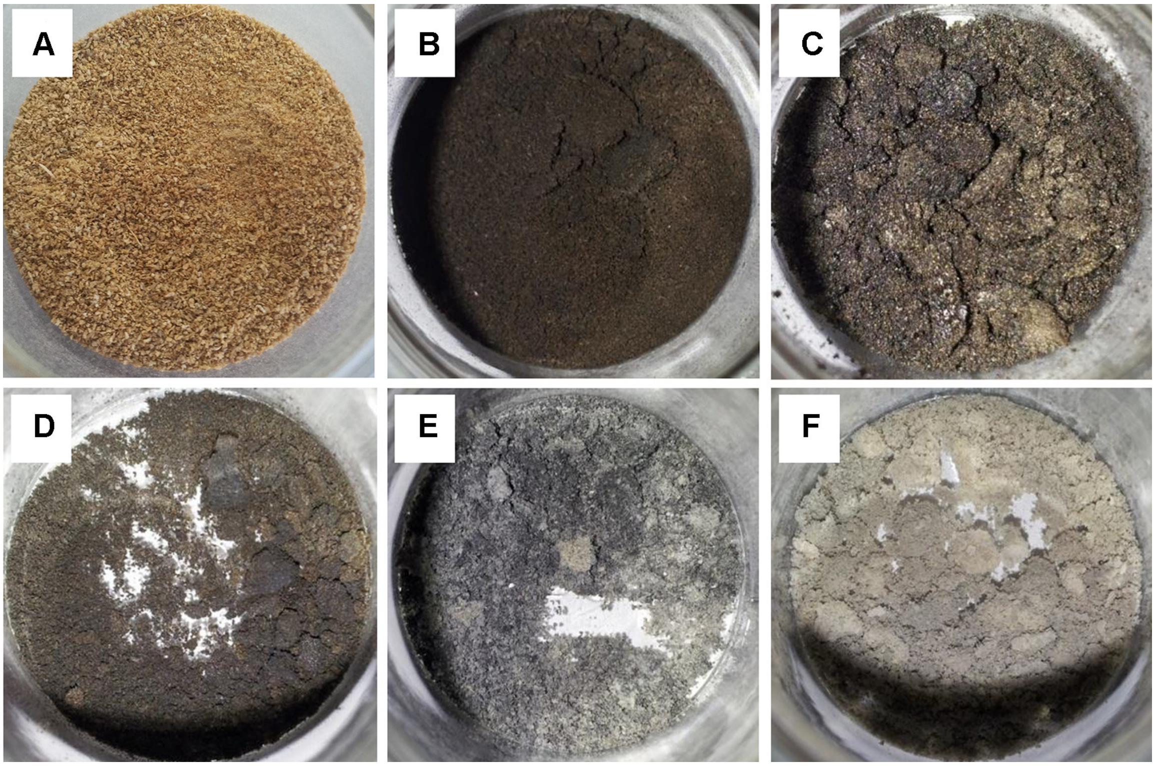

Fig. 3. Physical characteristics of the sago wastes before pyrolysis (A) and after pyrolysis treatment at different heating temperatures of (B) 250 °C, (C) 300 °C, (D) 350 °C, (E) 400 °C, and (F) 450 °C, respectively

Table 1
Optimum excitation wavelength required to achieve highest fluorescence emission from sago wastes treated with different temperatures.

Pyrolysis temperature (°C)	λ_{max} excitation (nm)	λ_{max} emission (nm)
250	332	436
300	310	429
350	313	400
400	315	390
450	308	410

phenol, cresols and additional heavier products will start forming [34], while severe decomposition of sample will only occur at temperatures beyond 300 °C [31]. Hence, this suggested the complete carbonization of sago waste sample into carbon rich residues at temperature beyond 300 °C. However, it was suggested that the heating temperature should be kept between 300 °C and 400 °C. Heating temperature beyond 400 °C may cause complete decomposition of sago waste into ashes instead of carbon rich residues.

In addition to visual observations of changes in the physical appearance of end-products due to temperature, the loss in weight in relation to the temperature factor was also investigated. As shown in Fig. 4, a trend was observed between the effect of heating temperatures and the percentages of weight loss in the starting precursors. The percentage loss was calculated based on the difference in mass of sample material before and after pyrolysis treatment. Based on the findings, the percentage of weight loss in sample material was found to increase along with an increase in temperature. The weight loss was the lowest when sample material was treated at 250 °C. As the heating temperature was set above 250 °C, significant weight losses of more than 60% from the initial mass were being observed which gave an indication of severe decomposition of sago waste into carbonaceous residues. It was discovered that the differences in weight loss between samples treated at 350 °C, 400 °C and 450 °C, respectively were rather insignificant. Hence, it was deduced that pyrolysis temperature set beyond 450 °C will have not much effect on the weight loss as most of the components in the waste may have been severely decomposed into ashy residues.

3.3. Optical characteristics of C-dots

The fluorescence intensities of sago waste samples treated at different heating temperatures were monitored using a spectrofluorometer. From the findings, samples after treatment at different heating temperatures have different excitation energy levels to give highest emission peaks (Table 1). Obviously when the carbonisation temperature was increased, the emission showed a significant blue-shift except for the one treated at 450 °C. The exception might due to the complete decomposition that formed ashes instead of carbon rich residues. As a result, the optical characteristic was not comparable with the other residues treated at lower temperatures. This blue-shift directly indicated that the size of the isolated C-dots was smaller for batches that were produced at higher temperatures. C-dots show size dependent emissions where the wavelength of the emission maximum of the C-dots varies sharply with their size [35]. Smaller size C-dots are reported to emit at shorter wavelengths while larger ones tend to emit at longer wavelengths. This suggested that thermal pyrolysis at higher temperatures were able to promote better and more efficient structure scissoring, breaking or depolymerising of the natural polymer chains into sub-microscopic clusters during the carbonisation process.

In terms of the fluorescence intensity, sago waste treated at 400 °C showed the highest emission intensity among the other samples treated at different temperatures (Fig. 5). This has been adopted as the optimum pyrolysis temperature used for the synthesis of highly fluorescing C-dots for all the subsequent studies reported here. Treatments with temperatures lower than 400 °C can lead to incomplete carbonisation, while higher temperature can cause severe decomposition of the organic structures in sago waste into ashes, which leads to the loss of the fluorescing property.

The origin of photoluminescence of the C-dots was still not clearly understood. It may occur as result of quantum effect from surface defects of C-dots, different emission energy traps on the surface of C-dots, band gap transition or caused by other mechanisms that have yet been resolved [1,6]. As observed in this study, the UV absorption profile of the synthesized C-dots at the optimum pyrolysis temperature (400 °C) was relatively featureless (Fig. 6). There was no distinctive absorption peak being observed. In addition to that, the Stoke's shift was found to be relatively narrow. The band maxima of absorption peak (excitation peak) and emission peak were close to each other which suggested that the origin of fluorescence emission of the synthesized C-dots may be due to band-gap transition. The full width at half maximum (FWHM) for fluorescence bands of all samples were evaluated to be >100 nm which were relatively broad as compared those reported in the literature review (<100 nm) [36,37]. It was suggested that synthesized C-dots has a relatively broad distribution in particle sizes which correlates well to the SEM analysis results of samples.

3.4. Potential application of C-dots in sensing of metal ions

Since the pyrolysis condition that produces C-dots with best fluorescence property has been identified, it will be of great advantage to leverage this unique optical property for a useful end-application. In view of this, a study was carried out to investigate the potential of using the C-dots for metal ions sensing. This was motivated by the fact that fluorescence of C-dots is commonly being affected by highly charged species such as cations when in near contact, which such signal later can be quantitatively modelled to give analytical information. Besides, there are some studies that have successfully demonstrated the utilization of C-dots for metal ions sensing even though those C-dots have been synthesized completely from different routes and starting precursors [36].

The sensing potential was evaluated by monitoring the initial fluorescence intensity of the C-dots for possible significant changes once added with the metal ions. Metal ions that are commonly present in the environment especially in water sources were chosen for this study, which include Cu (II), Cr (II), Co (II), Ni (II), Al (III), Ca (II), Pb (II), Zn (II), Sn (II) and Hg (II) ions. Fig. 7 shows the effect upon addition of metal ions on the fluorescence intensity of the C-dots. Majority of the metal ions added had caused the quenching in fluorescence of the C-dots; an initial positive sign showing the possibility to leverage C-dots for metal ions sensing. Among all the metal ions studied, the most significant quenching was observed for Cu (II) and Pb (II) ions, while Zn (II), Hg (II) and Ca (II) ions have showed the least effect on the fluorescence intensity once added. Low interference effect from Ca (II) ions would enhance the potential of synthesized C-dots as optical sensor for metal ions detection as Ca (II) ions were known to co-exist with other metal ions in the environment and present abundantly in biological system. The non-specific sensitivity of the C-dots was expected since pyrolysis treatment at high temperatures can degrade most of the organic layer on the surface of the C-dots, leaving it bare to the environment. Metal ions can come to close contact with the C-dots and induce different degree of disturbances on the initial fluorescent process of the C-dots, depending on their interaction affinity and electronic configuration. Surface modification of the C-dots can be performed to introduce specific chemical functional group on the surface, which deems to promote better selective interaction of the C-dots with foreign species present in the surrounding. For instance, C-dots capped with L-cysteine showed comparatively better interaction affinity towards Hg (II) ions against other metal ions

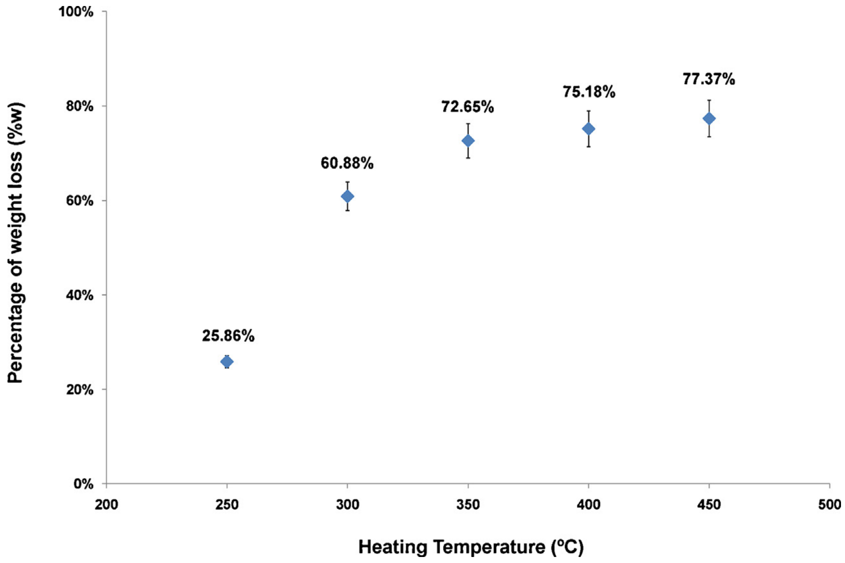

Fig. 4. Percentage of weight loss of the sago wastes after pyrolysis treatment at the prefixed heating temperatures.

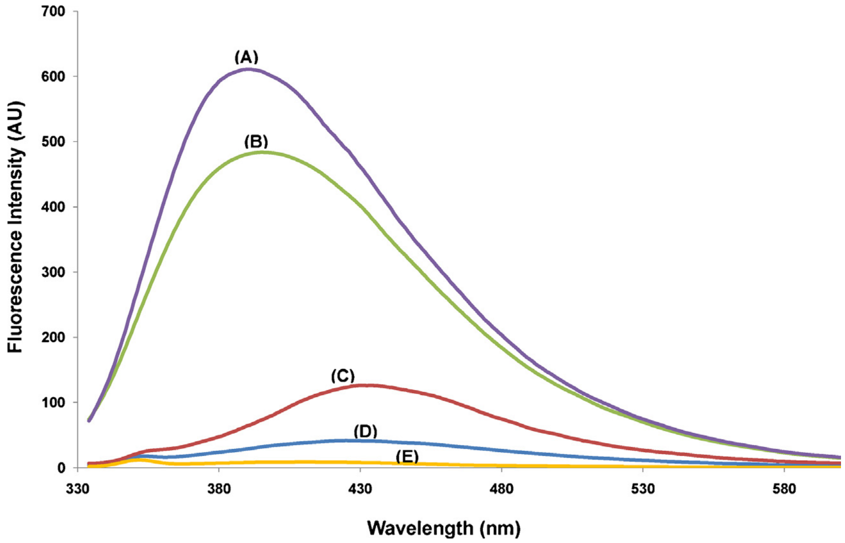

Fig. 5. Emission spectra of C-dots derived from sago wastes treated at (A) 250 °C, (B) 300 °C, (C) 350 °C, (D) 400 °C, and (E) 450 °C.

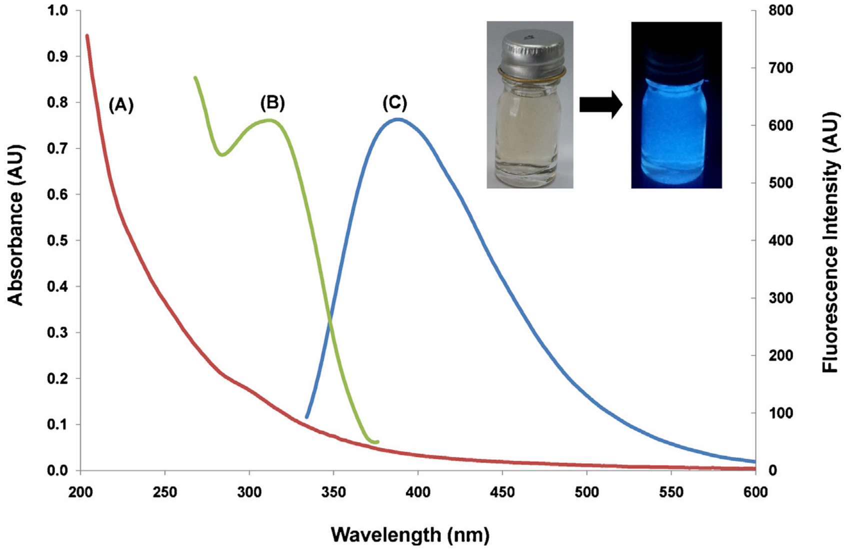

Fig. 6. UV visible absorption (A), fluorescence excitation (B) and fluorescence emission (C) spectra of C-dots derived from sago wastes treated at 400 °C. Inset shows the photos of C-dots viewed under visible light and exposure of UV (at 302 nm).

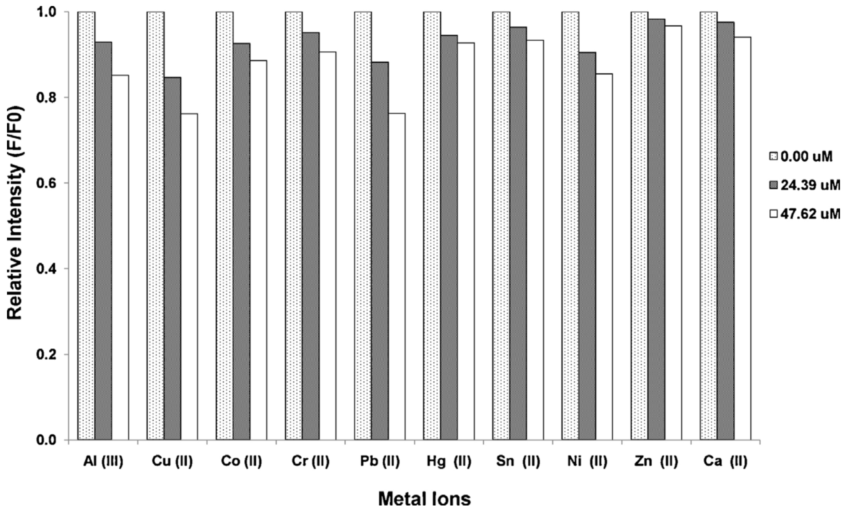

Fig. 7. The effects of addition of different metal ions at the concentration of 0.00 μM (blank), 24.39 μM and 47.62 μM, respectively on the fluorescence intensity of C-dots at 390 nm.

[38]. However, it is out of the scope of this work to investigate into surface modification of the C-dots. With the current C-dots isolated, it was suggested to be used to quantify on pre-treated samples containing single species of metal ion. In cases where pre-processing of sample is not possible, the C-dots still can be used for quantification via standard addition method. This can be performed by dividing the sample and spike the portions with increasing concentration of the analyte ions in an increasing amount, and the response of the quenching of the C-dots will be recorded. The calibration response constructed under such condition can eliminate the interference effects, leading to better accuracy result on the concentration of the metal ion of interest.

3.5. *Analytical characteristics of C-dots in sensing of metal ions*

Since majority of the metal ions tested have caused quenching on the fluorescence intensity of C-dots, its analytical characteristic needs to be evaluated and modelled before can be practically used as sensing probe for a targeted metal ion. For demonstration purpose, the emission spectra of a fixed amount of C-dots in response to the presence of increasing amount of Cu (II) and Pb (II) ions are shown in Fig. 8. It was obvious that both the ions were showing a concentration-dependent trend. Since it was a quenching process, standard Stern–Volmer relationship has been adopted to model the intensities recorded at the respective wavelengths of the maximum emissions. The relationship is represented by the following equation:

$$\frac{F_0}{F} = K_{sv}[C] + 1$$

where both F_0 and F from the equation denote the fluorescence intensities of C-dots before and after the addition of metal ions while $[C]$ represents the concentration of metal ions. K_{sv} denotes the Stern–Volmer quenching constant.

Based on the equation, a linear relationship between the fluorescence intensities of C-dots before and after the addition

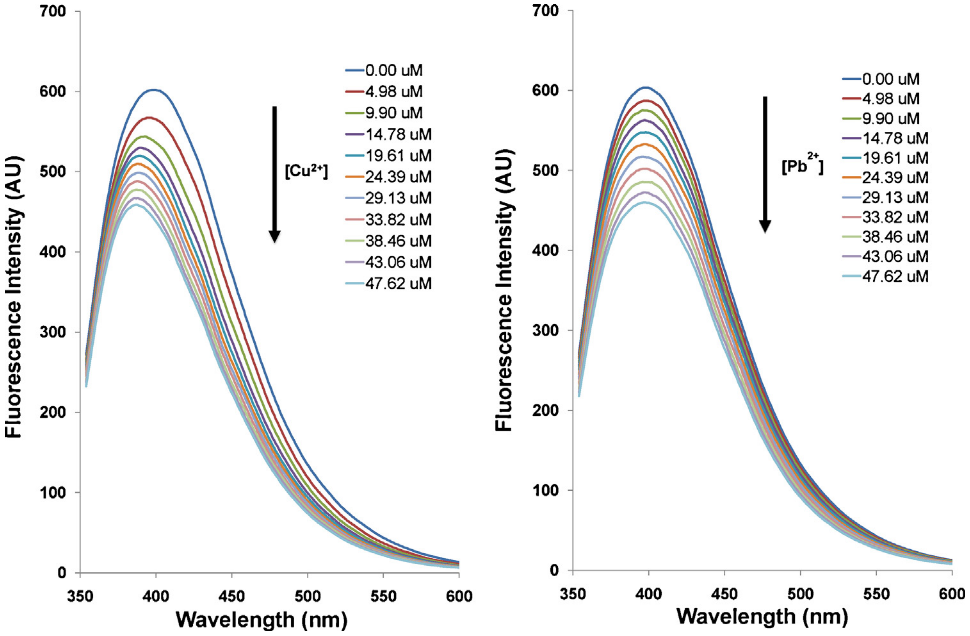

Fig. 8. The effects of addition of different concentrations of (A) Cu (II) ions and (B) Pb (II) ions on the fluorescence quenching of C-dots monitored at ~390 nm.

Table 2
Summary of R^2 value, Stern–Volmer constant (K_{sv}) and limit of detection for C-dots tested with different metal ions.

Metal ions	R^2 value	K_{sv} (M^{-1})*	Limit of detection (LOD) (μM)
Pb (II)	0.9948	6606.6	7.49
Cu (II)	0.9928	6362.0	7.78
Al (III)	0.9910	3698.9	13.38
Ni (II)	0.9940	3562.8	13.90
Co (II)	0.9900	2740.5	18.07
Cr (II)	0.9960	2089.8	23.69
Sn (II)	0.9951	1571.0	31.51
Ca(II)	0.9922	1423.1	34.79
Hg (II)	0.9954	1302.2	38.02
Zn (II)	0.9928	710.9	69.64

* Based on highest sensitivity to lowest sensitivity.

of metal ions, and the concentration of metal ions added was obtained. In accordance to the linear curves derived from the Stern–Volmer equation for C-dots added with different concentrations of Cu (II) and Pb (II) ions, the limit of detections (LODs) of the synthesized C-dots for the sensing of Pb (II) and Cu (II) were calculated to be 7.49 μM and 7.78 μM respectively. The calculation was based on $3\sigma/s$, where σ denotes the standard deviation of C-dots' corrected blank signals ($n = 3$) and s denotes the slope of the linear curve derived from Stern–Volmer equation.

Based on the similar approach performed on Pb (II) and Cu (II) ions, the analytical characteristic for all the other ions were evaluated as tabulated in Table 2. The metal ions evaluated to have the lowest sensitivity were Zn (II), Hg (II) and Ca (II). These ions are from the Group 2 and Group 12 elements with +2 oxidation state and having quite similar ionic radii. Interestingly, these ions are diamagnetic which eliminate the paramagnetic quenching mechanism with the C-dots. As a whole, it leads to the possibility of less effective quenching. As for the most sensitive species of Pb (II) and Cu (II) ions, the work by Stafiej and Pyrzynska [39] found that Cu (II) and Pb (II) ions have showed the highest absorption affinity towards the carbon nanostructure among other transition metals. Such strong affinity might be the reason of effective quenching observed since such close distance can easily disrupt the initial electronic conversion process within the C-dots to a non-radiative pathway.

4. Conclusion

This work has successfully demonstrated the conversion of sago waste into highly fluorescing C-dots via simple thermal pyrolysis method without any surface passivation. The heating temperature of pyrolysis was found to alter the degree of carbonisation of bulk sago waste into carbonaceous residues. The fluorescence of the C-dots was significantly quenched in the presence of various metal ions with better quenching effects observed in both Cu (II) ions and Pb (II) ions. Based on the current findings, the synthesized C-dots have the potential to be used as an optical probe for sensing of metal ions in aqueous media. Additional work on surface modification of C-dots can be applied to further improve their sensitivity and selectivity of detection.

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